

- XX. "Observations on the Functions of the Ganglia which are formed in the Posterior Roots of the Spinal Nerves." By ROBERT LEE, M.D., F.R.S. Received June 19, 1873.

(Abstract.)

The author gives a summary of the history of the discovery of the ganglia on the posterior roots of the spinal nerves, and expresses the intention of stating his views respecting the functions of the cervical and thoracic ganglia of the sympathetic nerve and the posterior roots of the spinal nerves in a future communication.

- XXI. "Researches in Circular Solar Spectra, applied to test Residuary Aberration in Microscopes and Telescopes, and the construction of a Compensating Eyepiece, being a sequel to the paper on a Searcher for Aplanatic Images." By G. WEST ROYSTON-PIGOTT, M.A., M.D. Cantab., Memb. Roy. Coll. Phys., Fellow of the Camb. Phil. Soc., the Royal Ast. Society, &c., and late Fellow of St. Peter's Coll., Cambridge. Communicated by Prof. STOKES, Sec.R.S. Received April 24, 1873.

The researches detailed in the present paper were commenced in May 1871. The results arrived at were largely obtained from using the microscope. Similar but less brilliant and more scanty appearances can be obtained with the telescope; but the very high power and ready adaptability of the former confers some advantages not offered by the latter.

In both, however, the same principles are illustrated.

A cone of rays of small angular aperture having the object-glass for its base in each case engages the eyepiece and emerges parallel, and the eyepieces are similar in each.

Peculiar facilities for studying solar spectra and their indications of aberrations and mechanical errors also are afforded by the former. The focal plane of vision may be employed to examine the effects of the interference of complex cones of light of large angular aperture, at least twenty times larger than those observable by the telescope.

The subject of the optical contacts of Venus at the coming transit confers peculiar interest on the nature of accurate definition of the final image presented to the eye-glass, especially as the new parallax will be entirely dependent on the keen definition of the four contacts.

The discovery by the writer of an unsuspected residuary aberration in the best microscopes, described in the Philosophical Transactions for 1870, renders it probable that some such a residuum still remains in telescopes; and this might impair the accuracy of such delicate observations as the apparent contacts between Venus and the solar limb. Eyepieces, abounding

generally with spherical aberration, require also particular attention. I have repeatedly observed a fine state of definition completely blurred merely by a change of eyepiece of the same power, which no mere focusing ameliorated, and which could only be corrected by a change in the convergent pencil passing through the objective intrinsically affecting its aberration.

Another branch of such an inquiry would be the *nature of the definition of an organic particle under high powers*, as every such research (such as the detection of the characteristics of diseased and healthy cells) may be resolved into the power of the microscope to define a single organic particle. Such particles are generally brilliant and refracting, and the errors of observation are unfortunately at present of a numerous kind. (Appendix A.)

On the Circular Solar Spectrum.

If a lens* be placed with its axis coincident with that of the microscope, and if its principal focus formed by the solar rays be examined by an instrument of the highest quality, we shall find that minute slices, as it were, of the *solar cone* present phenomena of rare beauty and order, dependent upon the quality of the examining instruments.

If two plano-convex lenses are placed with axes coincident, a good many coloured rings may be counted, but no black ones; so soon as their axes become oblique, the solar spectrum takes an intricate form, whilst the centre shows a brilliant cross (✕), very difficult to describe or represent by portraiture, but worthy of the highest photographic art of all the forms described.

This spectrum I venture to name the *circular solar spectrum*.

In my former research I had observed a flame-disk in a darkened room. This disk presented two or three diffraction-rings, similar to those of telescopic stars, but much broader.

The same method was attempted with the sun. Various objectives were used to obtain a solar miniature of the sun's disk.

Plain mirrors of glass silvered at the back entirely failed.

In order to form a pure and brilliant solar spectrum under the microscope, it occurred to me to take advantage of the principle of total internal reflection from a prism. I then constructed a prism-heliostat, which, acting in sunshine, presented an aerial miniature of the sun of great splendour (almost as dazzling as the sun itself) for half an hour, without further adjustment.

The prism-heliostat was furnished with a crown-glass double-convex lens, itself being of flint; and other lenses of less focal length could be attached to diminish or increase the diameter of the primary image of the sun, which, as the focal length generally used was 3 inches, gave an image $3 \sin 30'$ in diameter, or one fortieth of an inch nearly. In some cases object-glasses and eyepieces were placed in the solar rays emanating from the prism.

* This term of course includes every form. Of concave lenses, however, only very small ones can be conveniently examined.

Received by an inverted object-glass of the finest quality at a distance of 200 inches, the solar disk could be further miniaturized to any desirable degree of minuteness. A theoretical diameter of sixteen millionths was found convenient. To moderate the overpowering brilliance of such a spectrum directly viewed, dark slides of graduated neutral tints were at first used, and smaller primary disks were obtained by using deeper lenses at the prism.

When this minute spectrum is viewed with a high power (800 or 1000), the phenomena attending residuary errors, whether of achromatism, spherical aberration, or mechanical construction, are demonstrated with so keen a severity upon the handiworks of man as to throw all other methods into the shade.

Phenomena observed.

With the flame-disk formerly used* only two or three diffraction-rings could (as already remarked) be described; an extraordinary number of richly coloured rings of dazzling brilliance was now exhibited at the instant of bringing the solar disk into the plane of focal vision.

The most striking feature, amid so much effulgence, was an intensely black (*jet-black*) diffraction-ring encircling the central disk at the clearest focal point. The appearance of the rings changed every instant with the slightest change of focus, and their tints indicated the nature of the "secondary spectrum."

Upon closer inspection, my curiosity was excited by observing the shape of the primary or central black ring deviating from a true circular form, somewhat squared off, as though not consisting of one pure black ring. I then found, upon more careful examination, by change in the eyepieces, length of body, and "collar corrections," that it was composed of several excentric rings. The research, as one depended upon the fitful gleams of a spring sunshine, though tedious, was at this point enlivened with the outcome of an important fact, which will be more fully noticed further on [*viz.* that achromatism and aplanatism, in the best adjustable microscopes, at present were found to be altogether incongruous].

The same result, the enlarged disk, as described in my former paper was obtained.

The theoretical disk (exhibited on the stage of the microscope) appeared increased to nearly four times its proper size†.

* Phil. Trans. part ii. 1870, p. 595.

† Diameter of disk at prism $3 \sin 30'$ = .026

Diameter of miniature at 200 inches distance, reduced by $\frac{1}{8}$ -objective 1600 times = 0.000016

$\frac{16}{1000000}$

Observed diameter of solar disk, exclusive of its jet-black diffraction-ring = 0.000061

Estimated breadth of black ring = 0.00002

And 0.000016 : 0.000061 :: 4 : 1 nearly.

Three general features were constantly observed: the rings were seen either wholly or chiefly on one side of the solar disk, *i. e.* either within or without the focus, or nearly similar, except in colour, on opposite sides of the focal point.

If the rings were on one side a nebulous brightness occupied the other, into which the solar disk suddenly resolved itself on a slight change of focus; but frequently this nebulosity assumed a fine-grained or "engine-turned pattern." Occasionally two primary disks, each with its own system of rings, struggled for the mastery; and on changing the focus a chromatrope effect was produced by the expanding rings and their excentric intersections presenting an extraordinary loveliness of colours.

Another result somewhat startled me. In some of the best glasses the movement of the Ross collar-adjustment for the position of the front lenses entirely decentred the solar disk, so that here two appeared occasionally instead of one.

This phenomenon compelled me to infer that in many cases the collar-adjustment may become a greater source of error than the "thickness" of glass cover which it is intended to compensate, and that therefore excellent glasses, constructed with a permanent setting, are preferable, especially as a new compensation can be effected, as described p. 435*.

The frequent appearance of several disks at once in the field of view caused me to suspect that the axes of the component lenses of the objectives were not always coincident.

An Andrew Ross "quarter," marked 1851, though of good quality, displayed several irregularly placed central disks, which formed so many different centres of diffraction-rings.

A Berlin glass of good quality showed a much finer primary black ring, and a splendid display of several coloured rings edged with black; in a deeper focus four false centres appeared.

It will not be out of place here to detail a few experiments conducted with the object of verifying the cause of irregularity in the primary black, and the particular signs of chromatic and spherical residuary aberration.

One of the finest "immersion" one-eighths of Powell and Lealand, made expressly for me in 1871, the aberrations of which were small compared with those of glasses of their old construction, was now used to form the miniature solar disk on the stage as derived from the distant prism-heliostat.

I then examined the solar disk with a Powell and Lealand one-sixteenth immersion-objective (1862 make) adapted to water in 1870, a water-film being introduced between the glasses, whose axes had been carefully adjusted to coincidence.

Two overlapping disks were now seen: each formed its own independent diffraction systems above the best focus, and vanished below it with a confused bright halo.

* By means of the compensating eyepiece.

In order to determine the cause of this and to insure one axis in the solar disk, I substituted for the miniature-giving objective a convexo-plane lens of half an inch focus; and as this gave too large a disk, the lens of the heliostat was reduced from three inches to an inch and a half focal length.

[Unless the solar disk is reduced, the splendid phenomena of the rings cannot be properly developed. Their number and colours change with the slightest change of the plane of focal vision; and a very fine and delicate focal adjustment-screw, as well as great firmness in the apparatus, are essential to a successful display of the rings in all their wonderful beauty and complexity.]

The disk formed by the simple lens was now scrutinized with the Powell and Lealand celebrated immersion "eighth." Deeper eyepieces and a lengthened tube were employed to subdue the intolerable brilliance of the coloured rings; they now exactly filled the whole field of view. At first, used dry (improperly), this objective displayed a crimson solar disk edged with an intensely black ring encircled with a much broader bright ring, resembling the planet Saturn viewed perpendicularly to the plane of his ring. (Pl. II. figs. 1-3.)

Deepening the focus with exceeding lightness of touch, the central disk now became pearly white, set off prettily by its companion black ring and a number of pale lavender, pale rose-colour, and then brilliant outer circles of bright green, with intervals of orange-red, and, more outwardly, circles of red merging into ill-defined black.

But as the glass was constructed for vision through a film of water upon a thin glass "cover," I now attached (by moisture) a small fragment of cover, 0.003 inch thick, to the eighth, and delicately focused down upon the solar spectrum.

The solar disk then appeared single, circular, and bounded by a clear sharp black edge almost perfectly circular.

Upon examining the axis in different planes of vision or different sections of the solar pencil, I counted no less than forty-eight magnificent rings (including the black rings and interspaces) displayed at one time in the same field of view. Derived directly from the sun, with the brilliance belonging to total internal reflection, this rich assemblage of gorgeous rings, rivalling each other in prismatic splendour, set off by the sharp contrasts of jet-black well-defined borders, and shaded with the most delicate tints melting into one another with an exquisite softness, reminded me of the eloquent and glowing language of the late Sir John Herschel when describing the phenomena of diffraction. Doubtless, however, these appearances surpassed in intensity and brilliance those he described. (Pl. II. figs. 2 & 3.) Careful measurements were made. The diameter of the central disk $\frac{1}{16\frac{1}{3}\frac{1}{3}}$; breadth of its black ring $\frac{1}{50000}$.

My surprise was further increased by observing that, by lengthening the tube to increase power, I was enabled to cause each of the ruled

lines of a micrometric eyepiece (200 to an inch) to coincide exactly with the inner edge of each black ring; so that the breadth of each complete ring was exactly the same as that of the central disk, viz. $\frac{1}{16333}$ of an inch. (Pl. II. fig. 3.)

Slight changes in the colours of the rings were caused by the use of the Ross collar corrections.

In these researches a very near approximation to achromatism was signified by the whiteness of the central disk, the blackness of the fine rings contrasting finely with the intervening rings, which were then of a lavender-grey or very pale and yet brilliant lavender.

Destruction of spherical aberration appeared imminent when the rings, still coloured, were tolerably symmetrical on different sides of the finest focus with contrasting colours of the residuary spectrum. Mechanical errors were displayed by irregularity and complexity of form.

I shall now venture to give some particulars of the circular solar spectrum thus formed (as described) by a convexo-plane lens in a beam of sunshine examined by a high-quality immersion-objective armed with a small piece of broken cover attached by the cohesion of water.

*Description of the Rings of the Circular Spectrum of a
Convexo-plane Lens.*

Coloured rings.		Intervals.	
Solar disk	 White.	Primary ring	 Jet-black.
Ring II.	 Pale lavender.	Secondary ring	.. Black.
" IV.	 Lavender.	Third ring	 "
" VI.	 "	Fourth "	 "
" VIII.	 "	Fifth "	 "
" X.	 Pale rose.	Sixth "	 Dark red.
" XII.	 Bright green.	Seventh,	 "
" XIV.	 "	Eighth "	 "
" XVI.	 "	Ninth "	 "
" XVIII.	.. "	Tenth "	 Black.
" XX.	 Dark orange.	Eleventh ring	 "
" XXII.	.. Deep "	Twelfth "	 "
" XXIV.	.. " "		

Each of the rings, including the companion black or dark rings, appeared exactly of the same breadth, viz. 61 millionths of an inch, or nearly double the length of the wave of the extreme red ray; whilst the breadth of the primary black ring was nearly that of the wave-length for the line F in Fraunhöfer's spectrum, viz. 0.0004606 millimetre, or, since the French metre is in English inches

39.37078984,

it corresponds to 52256 waves to the English inch.

The delicate measurement of the primary black ring and disk was verified by a recording eyepiece micrometer. With this and the objective used it was found that one thousandth of an inch on the stage measured 1138 divisions, *i. e.* eleven turns of the divided head and $\frac{38}{100}$ of a turn. One division therefore represented

$$\frac{0.001}{1138} = \frac{1}{1,138,000} = \text{nine ten-millionths nearly.}$$

On estimating the breadth of the primary jet-black ring, and using a ruled glass micrometer, as I could detect no difference in the breadths of each ring, I felt justified in dividing the total diameter by the number of rings in order to obtain the breadth of one, which gave $\frac{1}{16333}$. A much deeper point in the axis showed a very deep blue central haze, paling outwardly, and then melting into a final red fringe.

The precision of the mechanical construction of this fine objective was thus revealed by the use of a simple convex lens of crown glass. Any deviation from accuracy was at once detected by the converging pencil of the plano-convex lens, consisting of shells of rays of various refrangibilities, having their several foci arranged along the axis. As this axis was necessarily single and unique, the interference phenomena, especially the sharpness and intensity of the jet-black rings, could only be so superbly exhibited by the best glasses. Inferior glasses blurred them and dulled the rich beauty of the colours.

Contrasting with this the performance of a variety of glasses, both English and foreign, very peculiar appearances arose which doubtless indicated grave errors of construction. I will venture briefly to mention some of these:—

- (I.) A variety of spurious disks oddly arranged were displayed.
- (II.) The beauty of the rings was entirely marred; and
- (III.) Very few rings could be developed, and sometimes no black rings whatever (Pl. II. fig. 7, and Pl. III. fig. 14).
- (IV.) Notched, grained, and spotted; the rings were sometimes irregular in shape (fig. 12).
- (V.) A multitude of fine black excentric rings, evidently arising from different centres, were seen upon a leaden-grey field surrounding the central disk, the confusion of the rings causing a bad achromatism.
- (VI.) An “engine-turned pattern” was not unfrequent, degenerating into a peculiar grained and mottled appearance.
- (VII.) A majority of the glasses were overcorrected spherically.
- (VIII.) Achromatism and aplanatism in our best adjustable glasses were found to be altogether incongruous.

As this result was alluded to at page 428, I proceed to relate the circumstances of the observation. I constantly found in pursuing these researches that either achromatism was sacrificed to aplanatism, or that the attainment of achromatism destroyed the brightness and truth of aplanatism. I may relate the following experience.

Whenever in watching the heliostat the sun was clouded over, as

alluded to at page 428, the microscopic miniature-perspective of the room and distant apparatus reappeared; and after various adjustments I obtained a perfect definition, free from mist and as clear and sharp as that of an opera-glass. The prism and lens of the heliostat then gave a pretty picture of the passing clouds, as well as the small details of the distant objects; but the instant the sun began to shine, before the rings dazzled the sight, every shining point appeared haloed with a corona of orange and red. I now turned aside the prism: then every polished point in the full sunshine exhibited the same halo. Again in the shade, the picture resumed its sharp definition. Waiting again for the sun, forth shone the orange haloes. The corrections were diligently plied till the halo nearly disappeared. The sun passed behind a cloud. To my astonishment the former sharp clear prospect was now *bedimmed with a general white mist, obscuring all the details before so beautifully clear*. The appearance of this white mist, *above the best focal point*, whenever achromatism was attained by varying the adjustments of the screw collars, now convinced me that the modern English glasses, when rendered achromatic, beget a residuary spherical aberration, obscuring delicate structures (such as I propose to describe further on) by a white mist, corresponding to spherical overcorrection, viz. the condition of the marginal rays for white light cutting the axis at points further from the centre of the lens than the central rays, and that until this fact is acknowledged an insuperable bar to the finest definition will continue to exist. (Pl. III. figs. 8 & 9.)

Dr. Colonel Woodward, U.S.A., having taken up the research, declares he found it impossible to photograph the most difficult beaded objects unless, upon examining their image on a white screen, he represented the beads red upon a blue ground; then, using a solution of the ammonio-sulphate of copper to absorb the red rays, and then only, could he photograph the results I had described * (M. Micr. Journ.).

Residuary spherical aberration, it thus appears, is the chief cause of

* In confirmation of the same principle the late Rev. J. B. Reade, F.R.S., wrote¹:—"Dr. Pigott has made also a very decided advance in the better correction of residuary aberration, a point which has, I believe, been almost completely ignored (nay even denied), until recently, by accurate observers as well as distinguished opticians. From my own experience in Dr. Pigott's studio, I have no doubt that his colour-test—a most interesting feature in his experiments—is the result of his finer balance of the aberrations . . . This new fact is one of the most striking phenomena in microscopical science of the present day. . . ."

"Whether this colour-test is explained on the theory of vibrating wave-length corresponding to the infinitesimal thicknesses of films . . . or upon their radiation, refraction, and internal reflection of the spherical beads of which all scales and diatoms appear to be built up, are questions so recondite as to be worthy of the consideration of the most advanced physicists of the day."

As residuary aberration is still denied, I may be permitted to quote 'The Student'

¹ Popular Science Review, p. 147, No. 35, 1870.

the difficulty experienced in defining organic particles—such as the molecules of physiological cells, blood-disks, mucous globules, and the discrimination of many forms of disease. It will probably remain uncorrected until opticians and observers abandon the false standards of definition still in vogue. If, then, it is at present impossible to avoid a residuary spherical aberration, whilst attaining very perfect achromatism, in the microscope, the finest definition will be obtained by stopping out the most obnoxious rays, either by using a monochromatic ray which suits the aplanatism, or using *bluish-green or blue glass* * to pale the red rays ; for glasses may be aplanatic to one ray and not to another of a different refrangibility.

Before concluding this part of the paper I may be allowed to make a few practical conclusions for those who may wish to follow up this line of research :—

1. As stated in the paper “On a Searcher for Aplanatic Images,” regarding a convex lens as undercorrected, undercorrection is shown by the appearance of the rings below or beyond the focal point and evanishment into mist above it.

2. Similarity in the rings on both sides (with change of colour also) denotes a balance more or less delicate of the aberrations.

3. An excentric position of the solar disk and a crowding of the rings more closely on one side than the other of the circular spectrum denotes parallelism, but non-coincidence, of the axes of the convergent and divergent pencils (figs. 28 & 29).

4. Rare and beautiful forms, resembling parachutes, vases, or comets, made up of ellipsoid, parabolic, or hyperbolic diffraction-lines, denote obliquity (figs. 16–34).

5. Their form depends on the nature of the aberrations present, and the mode of arranging the axis of the cone of rays forming the solar disk.

6. Inaccurate centering of the component lenses, either at the heliostat or in the observing or miniature-making objectives, is shown by “excentric turning” patterns and the appearance of two or several central disks at the smallest focal spectrum.

7. The apparatus necessary to display these brilliant phenomena must be exceptionally heavy and steady, and the fine adjustment should have a screw 100 threads to the inch, as the ten thousandth of an inch in the axis of observation completely changes the aspect of the phenomena.

In none of these experiments did the supposed achromatism bear the severe ordeal of the circular solar spectrum. By no arrangements could

of February 1870. It states that the writer “has told very plainly two startling and unwelcome *truths*. First, that observers have not seen their favourite test-object properly ; and, secondly, that their best object-glasses are afflicted with sufficient spherical aberration to render the structure which he describes invisible . . . and that all *difficult seeing* is in some suspense through these researches.”

* Appendix B.

colour be made to disappear. A white centre and exceedingly black rings, interspaced with a pale lavender and rose-colour, were the nearest approaches to perfect achromatism which I could produce.

On the Aberrations of Eyepieces, with suggestions for forming a Compensating Eyepiece for Microscopes and Telescopes, on the principle of searching the axis for Aplanatic Images.

The Astronomer Royal has given an account of a trial of several kinds of eyepieces and some of their bad effects*.

The use of a solar disk formed by an eyepiece fixed close to the prism-heliostat deprived of its lens, and examined by the method already described by means of accurately corrected objectives, places the achromatism of the eyepiece under a severe scrutiny. Very rich and beautiful colours are developed in the solar rings (previously obtained as pale as possible), corresponding to the extent of the chromatic errors. A Huyghenian eyepiece was placed close to the heliostat, so as to form a brilliant disk of the sun; the adjusted spectrum-apparatus immediately flashed with brilliant-coloured rings, before this appearing pale lavender and white.

During the use of the searcher for aplanatic images, it occurred to me to investigate the effects of pushing the eyepiece gradually nearer the object-glass without a searcher.

I discovered that, when within four inches, the definition showed violent undercorrection.

I now conceived the idea of substituting a traversing movement of the eyepiece, especially for glasses unprovided with a Ross collar, as a correction for thickness of cover.

A very firm sliding-tube was constructed; and I now found I had substituted a range of several inches, as a correction, for that of a few hundredths of an inch used in the Ross adjustment.

Experiment.—Adjusting the apparatus and the screw collars of the objectives for severe testing, a bunch of small glass drops, of diameter 0.04 inch, was suspended in front of the heliostat, so as to present a minute image of the sun. The searching eyepiece being placed at 10 inches distance from the stage of the microscope in the plane of which the solar disk is formed, and the minute solar disk observed in a state of balanced corrections, it was found that as the eyepiece was traversed towards the disk it became gradually more and more undercorrected.

It now became evident that this movement was, upon a large scale, equivalent to the effect of the Ross collar movement upon a minute scale.

It now occurred to me, as a thick cover and a water-film overcorrected

* *Astronomical Notices.*

an objective, that a dry objective might in many cases be transformed into an "immersion" simply by advancing the eyepiece; also that a sufficient variation of interval between the front lenses might in many cases enable a dry lens to act as an immersion.

[The immersion principle is valuable for the increased volume of the cone of rays radiant from the illuminated particle mounted in balsam, a much larger pencil reaching the objective *viâ* water than can possibly be effected *viâ* air, the "critical angles" of total internal reflection which determine the form of the caustic being so much larger in passing from glass into water than into air. I have shown elsewhere that the volume of the cone of rays transmitted from a radiant particle placed in balsam and surmounted with a thin glass cover is about four times greater *viâ* water than *viâ* air; that result is explanatory of the greater brightness of the immersion lens.]

The question of the spherical and chromatic aberrations of eyepieces has occupied the attention of the most distinguished mathematicians, and may theoretically be considered nearly exhausted; yet the practical detection of its existence is known to few, as it is liable to be mixed up with the objective aberration. The methods described are equally applicable to eyepieces as to objectives. (Appendix B.)

The construction of a compound compensating eyepiece which should be almost perfectly free from this residuum next engaged my attention.

From the discovery that the advance of an eyepiece towards the objective caused a violent *undercorrection in the refocused objective*, it became evident that a *shortened* microscope could be employed as a compound eyepiece nearly free from the usual aberrations, provided its object-glass were properly *overcorrected*, as compared with its performance at the usual standard distance of ten inches.

The new eyepiece is finally corrected on the circular solar spectrum (herein described), being regarded and treated as a real microscope. Its object-glass, considering the exceedingly small pencil engaging it, may conveniently be formed of slightly overcorrected achromatic lenses, compensated by a variable interval. I have found an inch focal length sufficiently deep, mounted with a low eyepiece. The substitution of this compensating eyepiece for the ordinary deep Huyghenians afforded that degree of comfort in observation corresponding to enlarged pencils.

After adjustment it is quite as applicable to examine the performance of telescopes as microscopes. The adjustment is thus accomplished:—

1. The instrument, mounted as a complete microscope, was adjusted for the most perfect definition on an uncovered object; and supposing the glasses A, B (adjustable by a variable interval) defined perfectly with the usual length of tube 10 inches, they require overcorrection* or separation for a shorter tube of 6 inches.

* Considering the small angular aperture, a single set of achromatic lenses might be

2. Various eyepieces were inserted, and the lenses A, B separated or closed more or less till the most perfect definition was attained.

3. Now, regarding the instrument as a perfectly corrected compensating eyepiece, it is transferred to the tube of another microscope, the objective of which is again adjusted by the screw-collar for the most distinct definition.

Tested on the principles glanced at in this paper, the corrected compensating eyepiece, free from the usual aberrations, may be confidently employed to test the circular solar spectrum of a minute distant solar heliostat-disk, formed in its focal plane, by the objective also of a proposed telescope.

On new Adjustments for the Object-glasses of Telescopes and compensations for residuary variations.

Applied to telescopes the compensating eyepiece is adjusted somewhat differently.

The instrument having been severely tested for an uncovered object, and used for this purpose as a compound microscope (its front glasses A, B being considerably overcorrected when tried for ten inches), the telescope is directed to the solar disk formed at as great a distance as is attainable by a prism-heliostat; the condition of the diffraction-rings will then display the state of the telescopic objective.

If several eyepieces and adjustable lenses are applied in succession, under precautions (such as securing a sufficiently small and distant solar disk), the aberrations of the telescope can be accurately observed*.

A careful consideration of the compensations effected in the microscope,

- (1) by separating the objective lenses,
- (2) by separating the eyepiece lenses,
- (3) by traversing the eyepiece in search of aplanatic images,

leads to the conclusion that, provided the front lenses of the compensating eyepiece be separable more or less, and the distance between them and the eyepiece be somewhat variable, then a new correction for the telescope is given by also separating the component lenses of its object-glass by minute intervals.

To accomplish this accurately, sliding telescopic tubes, one carrying

constructed and employed; but their correction is much more tediously attained than by separable sets of lenses.

* The eyepiece recommended to thus test the solar disk formed by a telescope is to be used precisely upon the same principles as a microscope; the greater the aperture of the telescope the greater will be the power applicable, *i. e.* by deeper eyepieces and objectives, which must have much more widely separable lenses than usual for "cover correction," as regards screw-collar adjustments, if employed in order to compensate for shortness of body. The aperture employed by this eyepiece in all cases equals the angular aperture of the object-glass of the telescope at the focus of the eye-lens.

the flint glass and another the crown, are furnished with long rods terminating with similar screws with divided heads.

If on testing the telescope severely by applying a microscope accurately adjusted to the solar disk, diminished sufficiently by a distant inverted objective in front of a heliostat described, the telescope object-glasses be overcorrected, the separable lenses of the telescopic object-glass will require closing together slightly by moving the screw-heads through equal spaces; and, *vice versâ*, slight residuary aberrations will be also affected by changes in the compensating eyepiece. The tubes should be ground (in the manner of making levels) truly to preserve the centering of the objective lenses.

Another form of correction is the concave achromatic lens, now called the Barlow lens. If this lens be formed of an overcorrected combination, its effect on the final aberration will vary as it receives a larger or smaller pencil, *i. e.* as its position between the eyepiece and objective of a telescope or microscope is made to vary. The traversing principle here advocated has therefore several important advantages worthy of investigation, and may possibly form a correction for changeable refracting powers of the atmosphere.

In the compensating eyepiece a large visual pencil is substituted for a minute one and the same ease and comfort is obtained with it as if the linear aperture of the telescope were greatly enlarged. An ocular of one-inch focus may be used instead of another ten times as deep.

Slight changes in the over- or undercorrection of the telescope depending on the changeable density of the atmosphere may also probably be compensated by over- or undercorrecting this eyepiece.

Moreover the special aberrations of the eye-glasses may be ameliorated by a slight change of form and an alteration in the interval between them.

NOTE.—*June 25, 1873.*

The scarcity of sunshine this year has prevented me carrying out a complete series of experiments in telescopes. My excellent 8½-inch Browning equatorial (one of his very best) shows little spherical aberration. Two very good achromatic telescopes with the ordinary eyepieces gave imperfect jet-black rings, few in number, with the ordinary Huyghenians; but with the compensated eyepiece I counted six intensely black rings. The definition was excellent.

I trust observers with more convenient appliances and range of prospect will be induced to try a series of experiments on correcting residuary aberration in their telescopic object-glasses by the methods here laid down, and the writer will at any time be honoured by exhibiting to them some of the phenomena here described, as already done to Dr. Gladstone, F.R.S., and Mr. Beaumont, F.R.S.

APPENDIX.

A.—Definition of minute organic particles.

A new fiftieth immersion lens, price thirty guineas, has been made for me by Messrs. Powell and Lealand; with this glass, without any obliquity, and using a tube four inches shorter than usual and a B eyepiece, the upper continuous ribs of the *Podura* were resolved into strings of blue sapphire-like beads appearing perfectly circular. The interspaces between the markings at a lower focus showed lower strings of white beads.

Monads appeared blue, swimming about in the water used, and also lying in well-defined masses; some of them could be seen to rotate; the cilia were invisible, but the movements gave strong indications of them. —April 21, 1873.

A blue glass improved the definition. Coal-oil lamp and $1\frac{1}{2}$ -inch open condenser object-glass.

At present nothing is more difficult of definition in the microscope than an assemblage of minute refracting organic particles. Virtually forming disks of light, these display the diffraction-errors and phenomena more or less vividly. No English microscopist has yet succeeded, so far as is known to the writer, in displaying, in the apparently blank spaces, the beaded structure seen between the celebrated exclamation-markings of the *Podura* test-object. Here a closely packed mass of organic particles, highly refractive and transparent, obscure each other; brilliant points are swelled out exceedingly, for a theoretical solar disk one millionth of an inch * in diameter appeared as large as a disk the sixty thousandth. To define accurately bright organic particles, such as those of the smallest test-*Podura*, the molecules of cancer-cells and other diseased forms, and monads (minute atoms of metal by reflected light might also be named), is at present impossible; when such delicate forms are in quest, all rays of an aberrating character must necessarily be extinguished.

Illustration.—Examining with an excellent new $\frac{1}{50}$ immersion at sunset, as already alluded to, it was only when a peculiar bluish-green of the sky was thrown by an open excellent $1\frac{1}{2}$ -inch objective glass condenser upon the stage that the internal organic particles of a delicate *Podura*-scale became visible. Doubtless in this case the diffraction-spectra here had reached a minimum†. In the details given in the accompanying note several points are particularly worthy of notice—the use of an intermediate lens (amplifier), the sudden appearance of organic

* Easily formed by placing a minute lens before the heliostat.

† Dr. J. J. Woodward, U.S. Army Museum, has published a remarkable confirmation of this point. The existence of intercostal beading, first discovered by the writer in 1862 and published in May 1869, has been (and still is) disputed by English observers in no amicable spirit. He states:—

“Shortly after my paper had been forwarded I received a visit from Mr. Joseph

particles, monochromatic light, and the view of a higher focal plane than that which showed the markings.

B.—*Eyepieces.*

The spherical aberration of positive eyepieces may be examined as follows :—

The positive in an inverted position is placed under the stage, and forms an image of the solar disk for examination.

DESCRIPTION OF THE PLATES.

Circular Solar Spectrum.

PLATE II.

Fig. 1. Primary rings finely defined at the first visible focal plane.

Fig. 2. Secondary rings, at a deeper focus. The central disk should have been squared off.

Fig. 3. Exhibition of the greatest display of rings, each annulus having its own breadth equal to that of the central disk, which is a brilliant white, the succeeding lavender, rose-colour, and red rings separated by dark rings, the first few of which are jet-black.

Figs. 4, 5, 6, 7. Development of two disks instead of one; also of four irregular disks showing the existence of displaced centres and irregular diffractions.

PLATE III.

Figs. 8, 9. The miniature prospect of the distant window is displayed sharply in fig. 8. So soon as the sun began to shine, the blazing prism being quenched by turning it aside, every brilliant point became irradiated with an orange-red halo

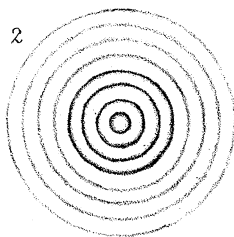
Beek, who is spending some months in the United States. He exhibited to me (with his fine high-power objectives) several slides of the scale of the *Lepidocyrtus curvicolis* [test-scale *Podura*] collected by himself from carefully identified insects. He aimed at the exhibition of the exclamation-marks, as such, using a right-angled prism, achromatic condenser, and small coal-oil lamp. Before leaving Washington he was so good as to give me one of these slides, indicating on it a scale which appeared particularly adapted to the display of the exclamation-marks. Certainly this scale, which was $\frac{1}{16}$ of an inch in length and $\frac{1}{64}$ broad, surpassed in the distinctness of its markings any of the scales of this species which have hitherto come into my possession. With central *monochromatic light*, the immersion $\frac{1}{16}$, and *amplifier*, I obtained a negative showing the exclamation marks better than any representation of the kind I have yet been able to obtain. I send herewith a paper print. The magnifying-power is 3200 diameters." (Dr. Woodward also favoured the writer with copies.)

"But immediately afterwards, with the same optical combination and magnifying-power, without any change in the cover correction, by simply rendering the illuminating pencil oblique, and *slightly withdrawing the objective from its first focal position*, I obtained a negative which displays the "bead-like" or varicose appearance of the ribbing more satisfactorily than I had previously been able to do." (Month. Micr. Journ., June 1871, p. 245.) [The writer has *italicized* the quotation.]

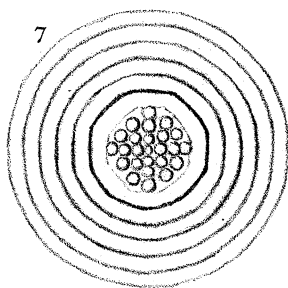
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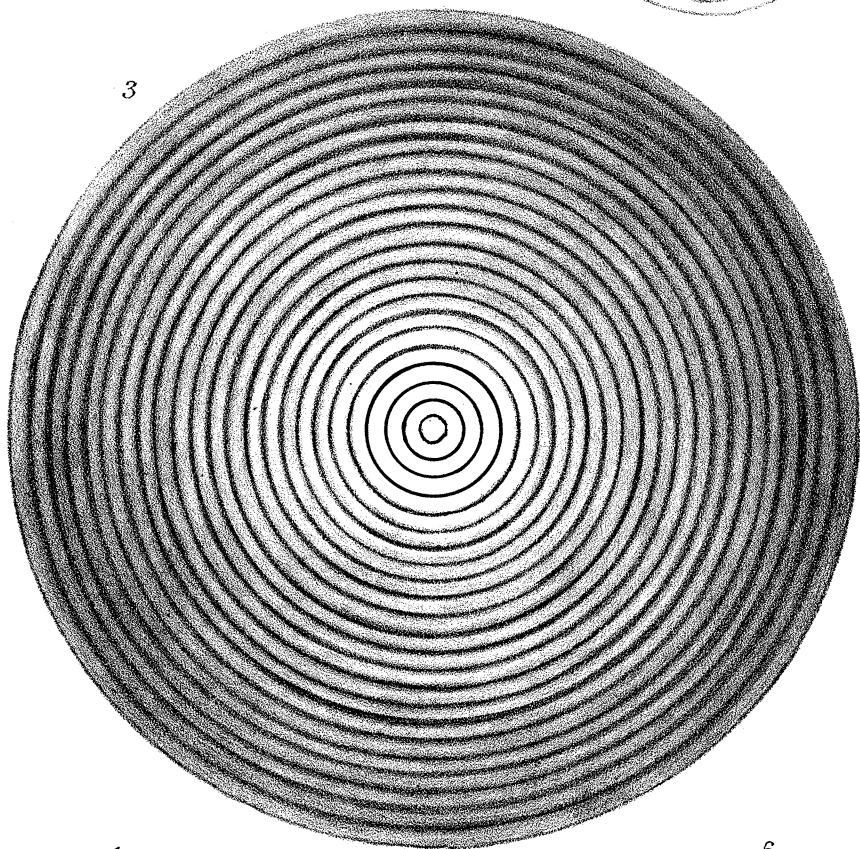
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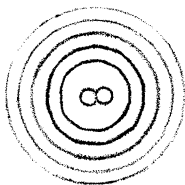
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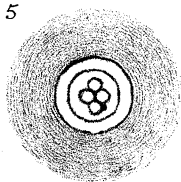
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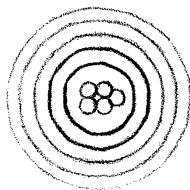
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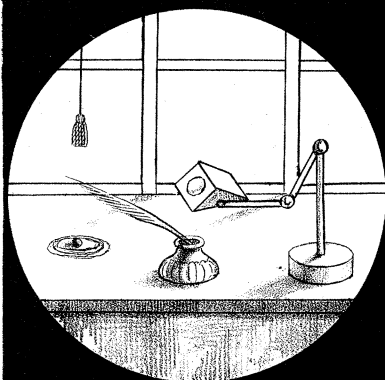


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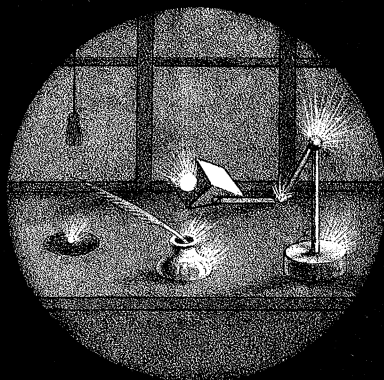


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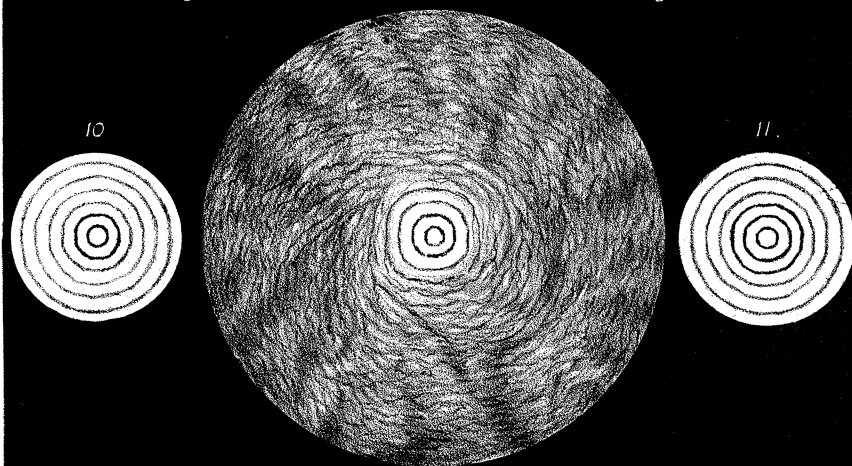




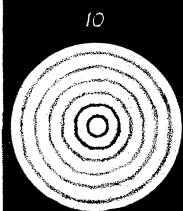
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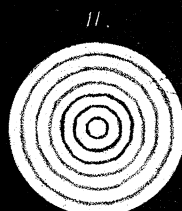
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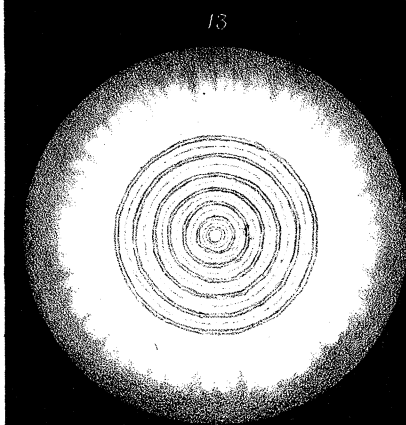
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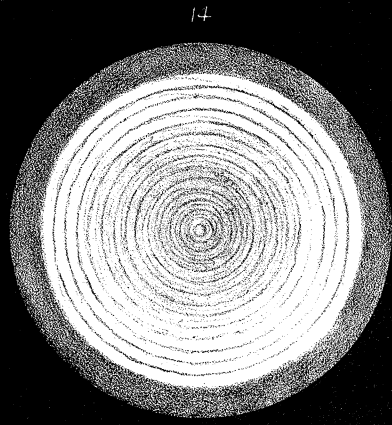
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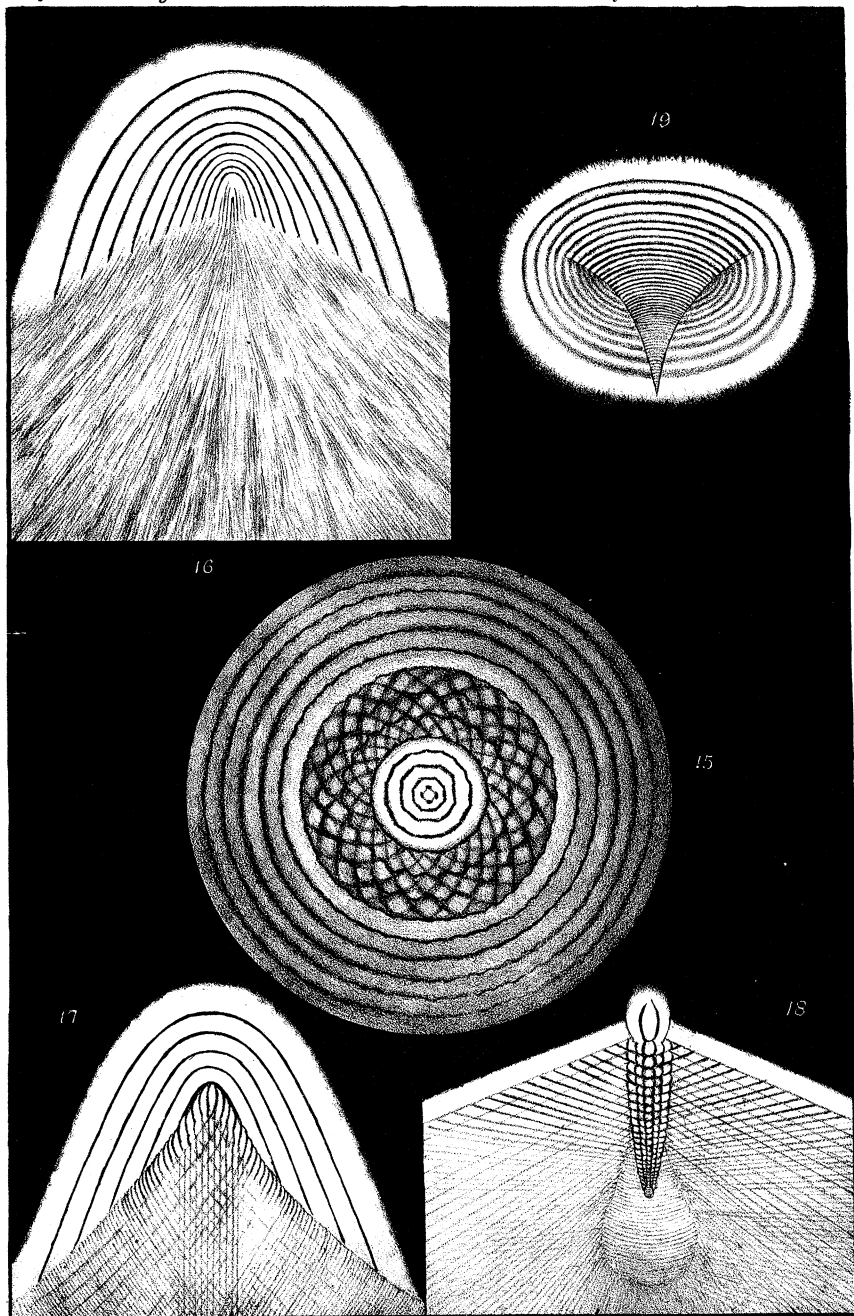
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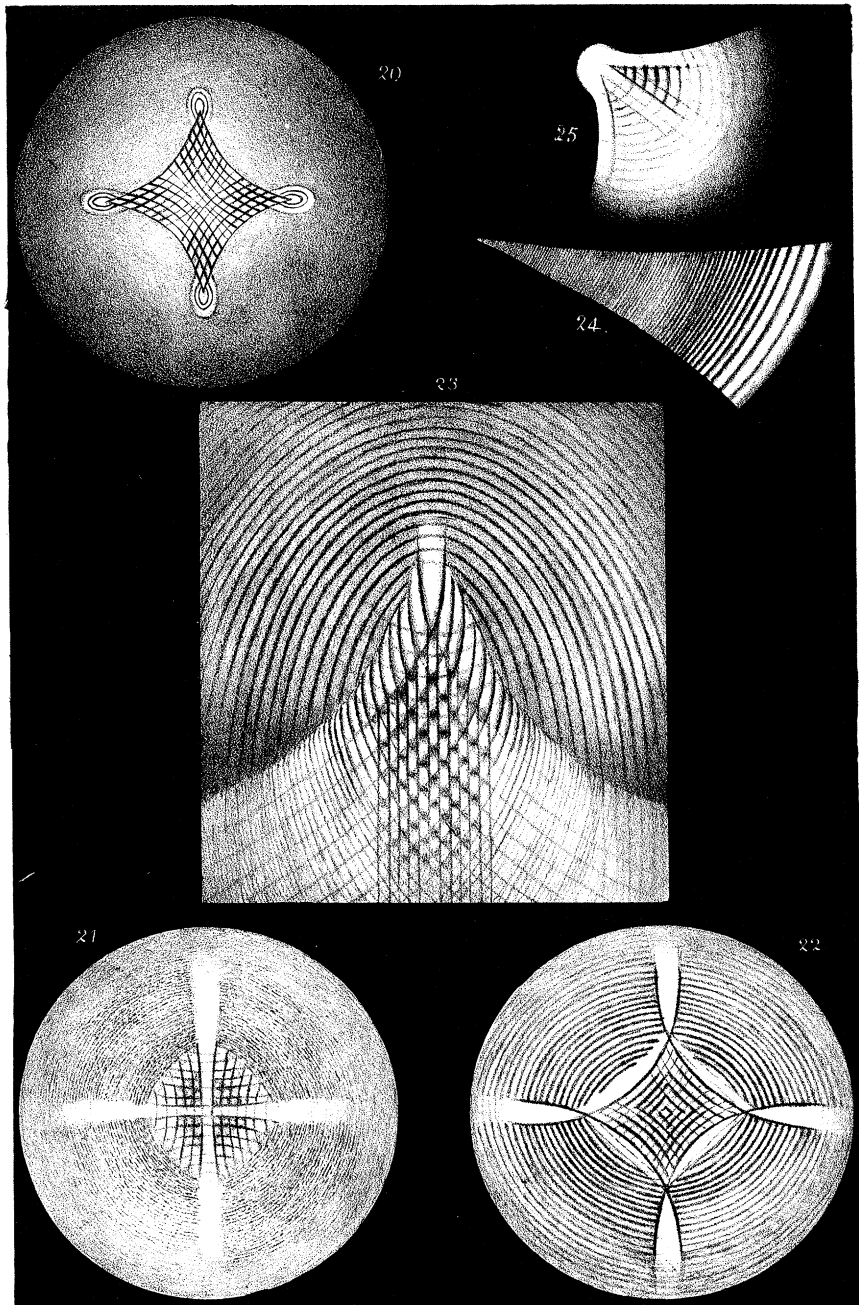


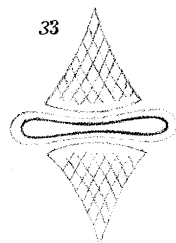
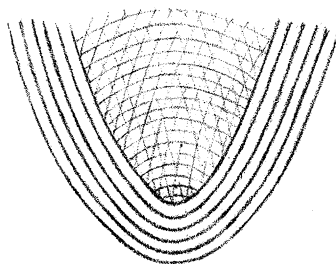
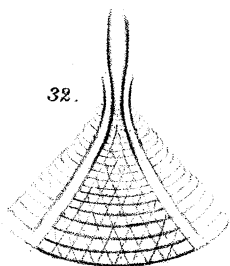
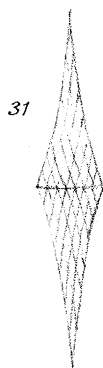
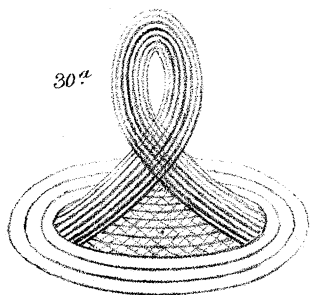
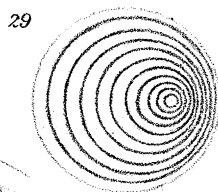
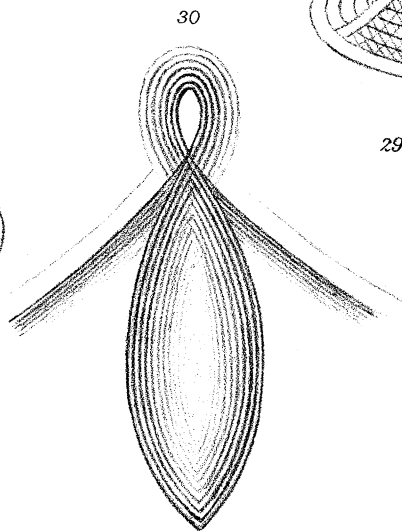
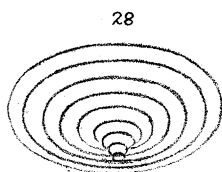
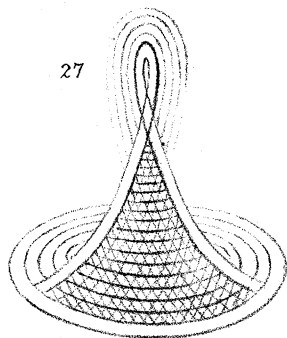
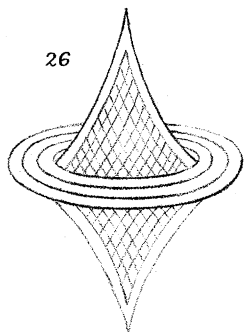
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Fig. 12 displays the very delicate engine-turned pattern and obscuration of the diffraction-rings by a badly constructed glass (cheap German).

Fig. 13 shows a delicate set of rings between the coarser, expanding by a change of focus in a different manner. The approaching halo and fog are well delineated.

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The next figures illustrate the effects of obliquity, the previous drawings exhibiting various effects during coincidence of the axis of the microscope with that of the miniature-forming lens.

Figs. 16 & 17 represent a very beautiful variety of hyperbolic diffraction-lines seen when the axis of the solar ray is inclined about 6 degrees to that of the microscope. Distance of heliostat 20 feet, magnifying-power 1000. Powell's best $\frac{1}{4}$ forms the miniature observed with best dry eighth.

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PLATE V.

Figs. 20, 21, 22. Best $\frac{1}{8}$ and $\frac{1}{4}$ plano-concave stage-lens.

The circular spectra here delineated are produced by slight obliquity, and represent the appearances at different focal planes. The colours are extremely brilliant, and the lines perfectly sharp in their tracery.

Fig. 23 shows the lines formed by the circular solar spectrum viewed with the greatest obliquity attainable, the elliptic lines representing a plane cutting both side of the cone of converging rays.

Figs. 24 & 25 introduce a new order of figures formed by placing a mercurial globule 10 inches from the stage, and placing the $1\frac{1}{4}$ -inch objective condenser with its axis considerably inclined (an angle of 15°) to that of the microscope; the images of the solar disk then took these and the forms in figs. 26-34, as seen with a microscope armed with a good eyepiece (Kellner 1-inch) and a fine $\frac{1}{4}$ objective.

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Fig. 34 is another form of mercurial globule, beautifully defined.

The figures displayed by the magnified artificial star for oblique reflection render it probable that the obliquely illuminated mercury globule, viewed directly in close proximity to the front glass of the microscope upon the stage, is a very imperfect test; and the methods here described are submitted as possessing very superior delicacy and convenience.

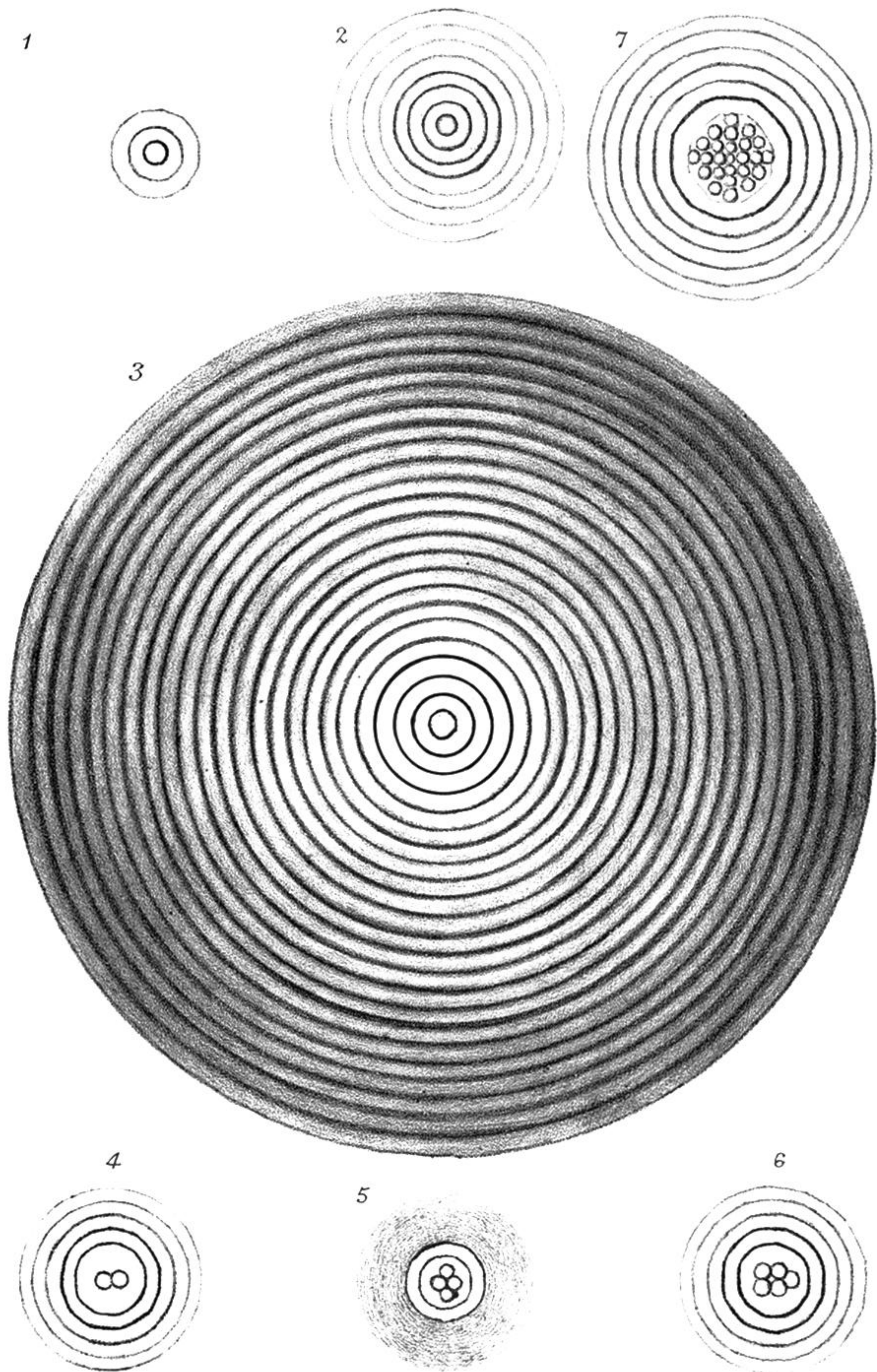
XXII. "On Comparative Vegetable Chromatology." By H. C. SORBY, F.R.S. &c. Received June 9, 1873.

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Introduction.

The study of colouring-matters as described in the following paper requires the use of a somewhat special kind of chemistry and of spectro-



Circular Solar Spectrum.

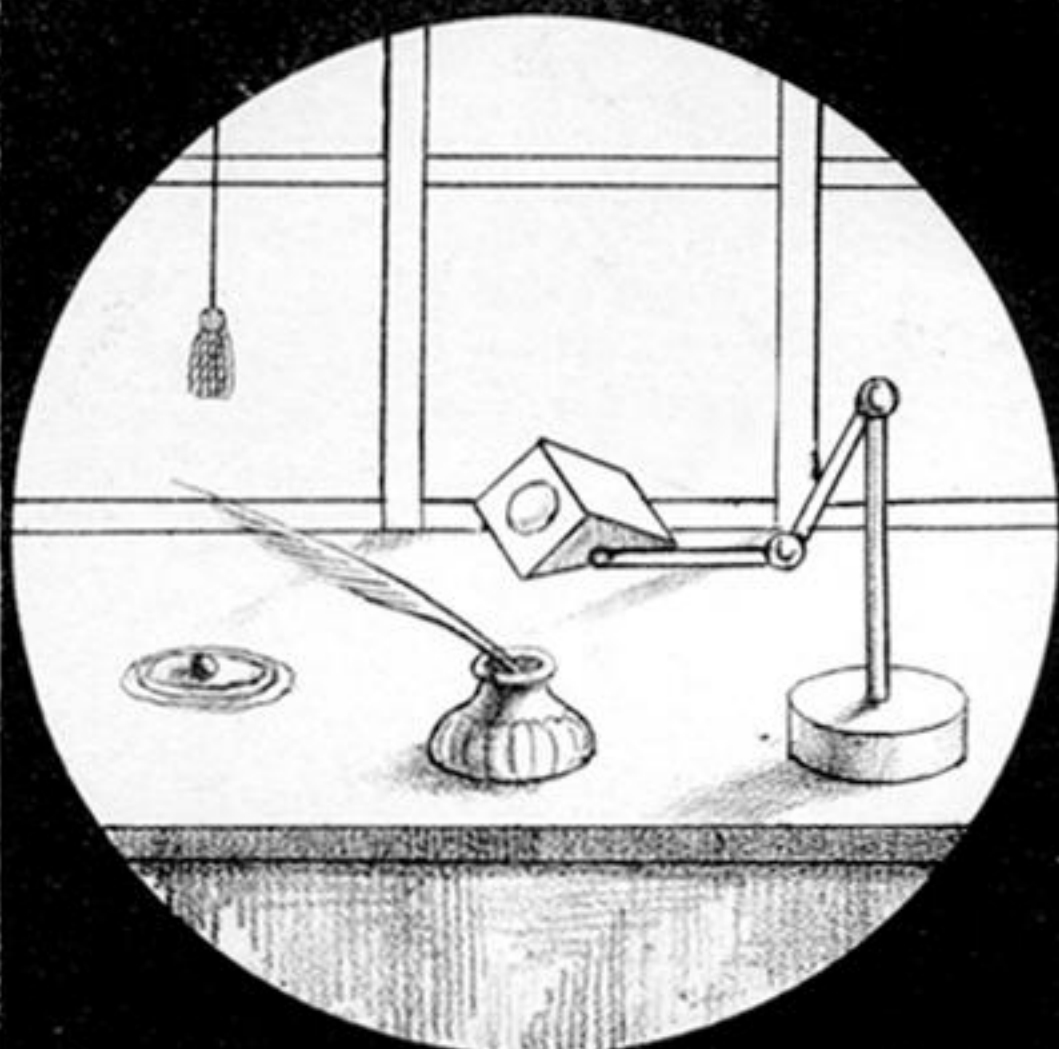
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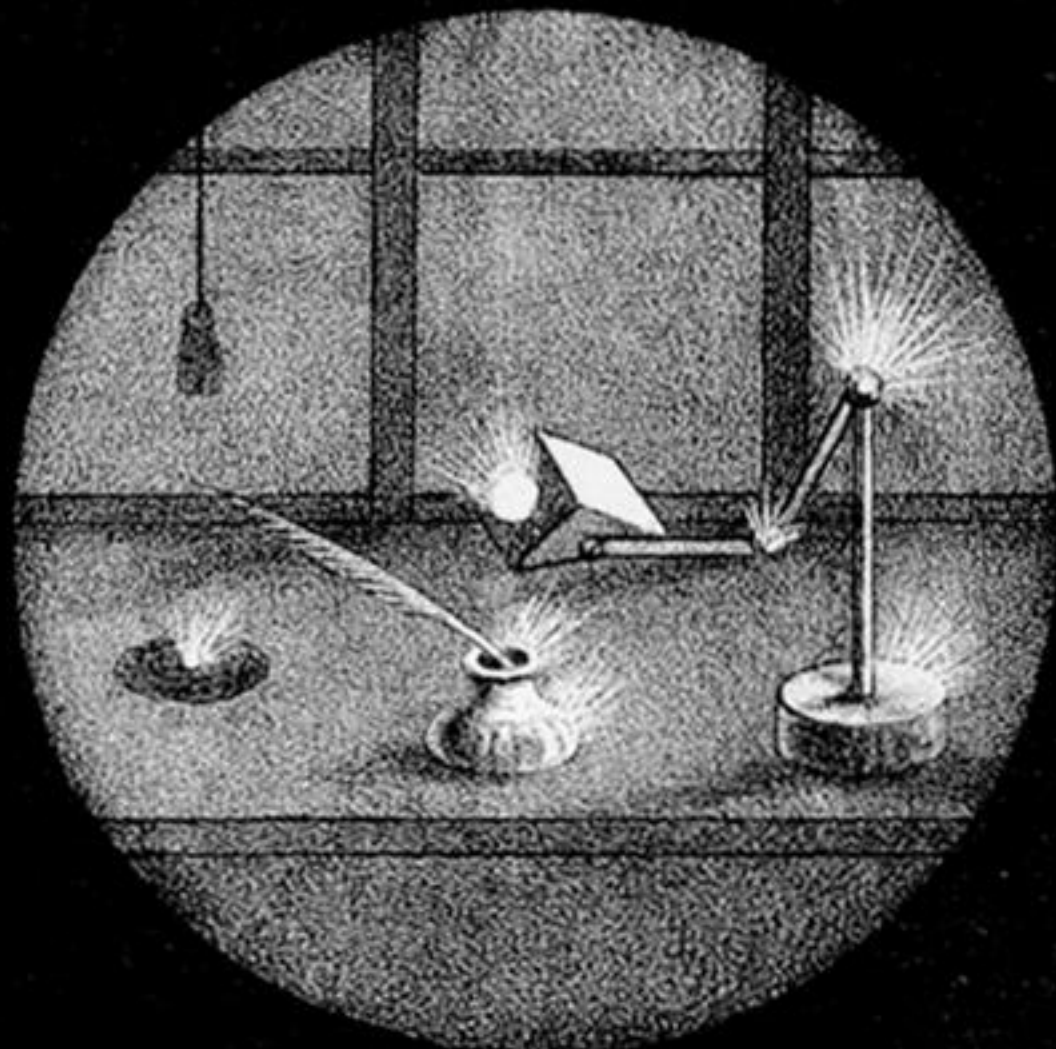
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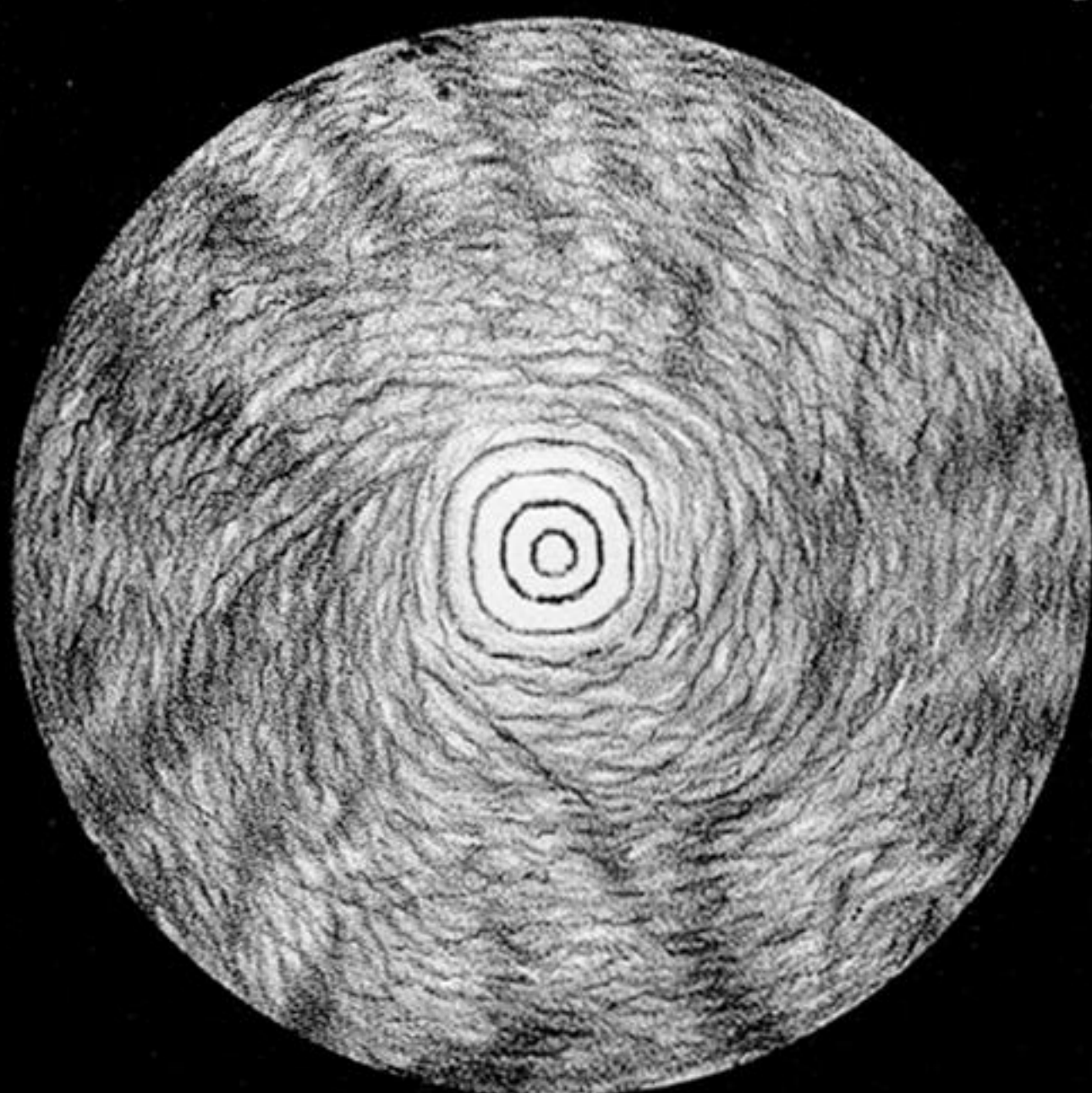
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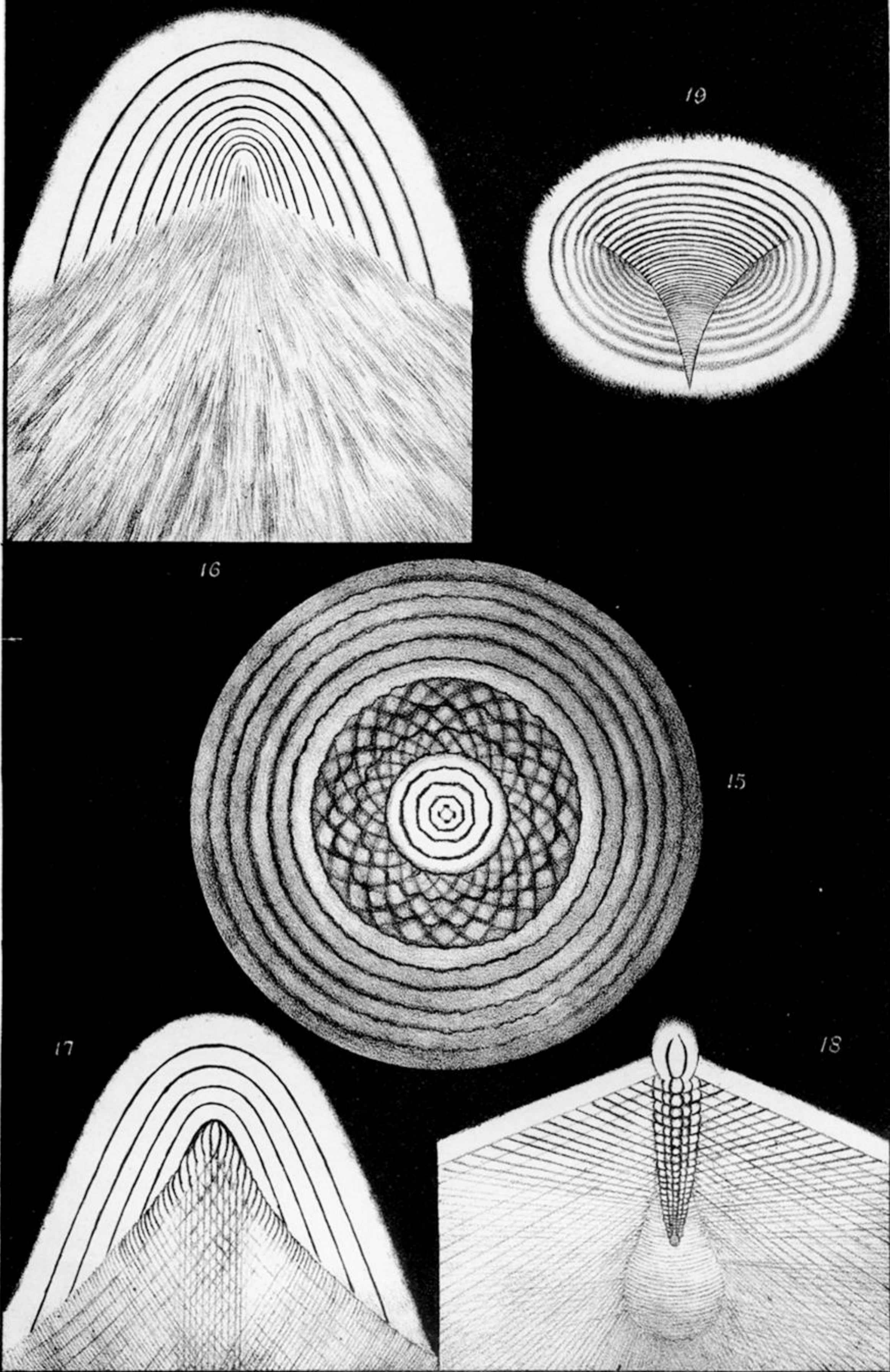
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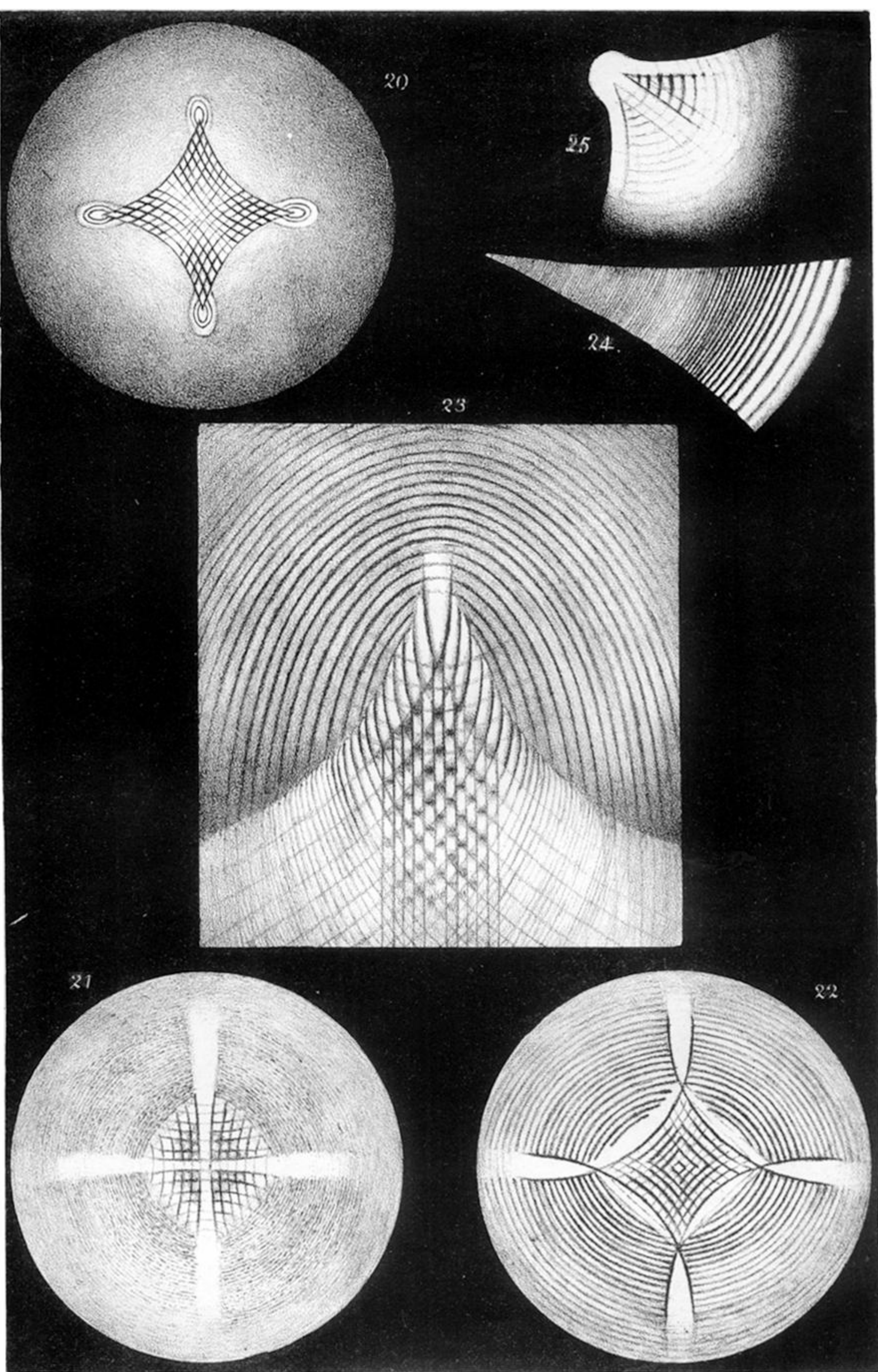
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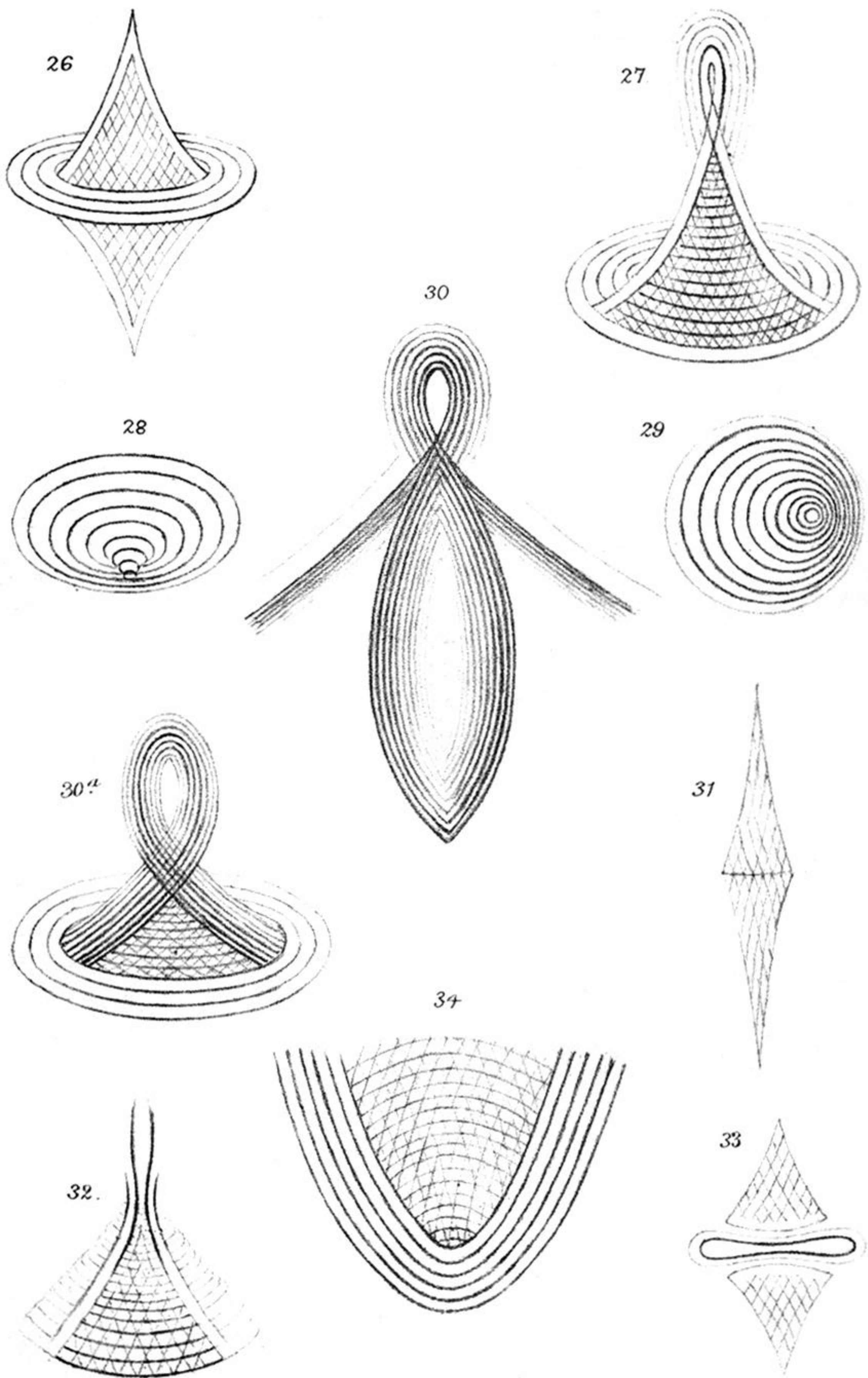
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